Robustness and True Performance of Demand Controlled Ventilation in Educational Buildings – Review and Needs for Future Development

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Abstract

Although theoretical studies show that energy use for ventilation purposes can be reduced by more than 50% with DCV compared to CAV, evaluation of real energy use demonstrates that this potential is seldom met. DCV-based ventilation systems must become more reliable to close the gap between theoretical and real energy-performance. This unfortunate experience with DCV seems to have many causes, including: unclear placement of system responsibility, inadequate specifications and hand-over documentation, balancing report not suitable for DCV, communication errors and lack of knowledge about DCV-systems among decision makers, designers and operators etc. Identified key factors for improvement so far are adequate specifications, hand-over documentation and balancing report for DCV and a clearly defined and placed responsibility for the overall functionality. This paper presents a recently started project that will last until 2013 and aims to develop and disseminate knowledge on systems with improved robustness.

Keywords: Demand controlled ventilation, Energy efficient, Educational buildings, Robustness, Target values, Occupancy, Control systems, Sensors, Communication systems

Introduction

There are many possibilities for the application of DCV and new knowledge about the importance of outdoor air supply, because of awareness of its positive effect on sick leave and productivity [1, 2] should lead to a wish to increase the outdoor air supply in comfort ventilation applications. This will further increase the demand for and profitability of, DCV-systems.

Demand controlled ventilation (DCV) can considerably reduce the ventilation airflow rate and energy use compared to constant air volume (CAV) ventilation [3]. This conclusion is supported by an inspection of 157 classrooms in primary schools in Norway [4]. On average, 74% of the design capacity is utilized when the classroom is in use, in terms of number of occupants. The classrooms are typically used for 4 hours on days with normal school activity. Theoretically, CO_2-sensor based DCV should reduce the ventilation air volume in the average classroom to about 43% of the corresponding air volume for a CAV-system operating with full airflow from 7 AM to 5 PM. The energy use for ventilation purposes is reduced to about 38% of the corresponding energy use for a CAV-system. Ventilation energy consists of fan energy and necessary ventilation heat after heat recovery. Comparison of perceived indoor climate in schools with CAV-systems and DCV-systems does not indicate that well designed CAV-systems add extra quality to the indoor climate [5]. Studies by Wachenfelt [6] support this conclusion. The purpose of extra ventilation with CAV-systems is therefore questionable as it basically leads to additional energy use when rooms are unoccupied.

CO_2-monitoring sensors have been commonly used for controlling the ventilation rate. Several field studies indicate that many CO_2-based demand controlled ventilations system do not meet design goals of saving energy because of poor sensor accuracy, [7]. More accurate sensors together with air flow rate measuring at room level, could even make it possible to "see" important demands such as: "how many occupants are in the room, and are the number increasing or decreasing", information important to optimize indoor environment. New CO_2-sensors with HoloChip have recently been introduced to the market. They are announced to have increased accuracy and long-term stability. Sensor performance and improved sensor requirements will be evaluated in this project.

Infrared occupancy sensors are a cheap alternative to CO_2-monitoring for controlling the ventilation rate. The control strategy is normally bimodal: The ventilation rate is reduced to a minimum when the room is unoccupied, and is increased to the design ventilation rate whenever the room is occupied. The occupancy sensor can also control artificial lighting and solar shading. IR-sensor based demand-controlled ventilation reduces the energy use for ventilation purposes in the average classroom to about 51% of the corresponding air volume for a CAV system operating with full airflow from 7 AM to 5 PM [4]. There are also IR sensors with a stepless output signal that is proportional to the activity level in the sensor's field of view, which is an approximate measure of the number of people in the room.

Case studies in Swedish schools have shown that IR-sensor based DCV can reduce the ventilation energy requirements by approximately 50% [8]. Persily [9] has found that DCV-CO_2 can reduce the energy use for ventilation purposes from about 50 to 75% in a lecture hall. Both of these results are in good agreement with the results of Mysen [4].

Sørensen [10] has estimated the energy savings to be between 30 and 55% with DCV relative to a comparable CAV-system without being specific about the type of building. Drangsholt [11] found that the average occupant load in a university auditorium during the working period was about 36% of maximum allowed occupancy load.

Mysen's results [4] are from schools with a traditional classroom-based education principle. Since the input data for the study of Mysen were collected, newer Norwegian schools are built with more open-plan indoor solutions with individual and group based education. The decision as to which of bimodal IR-sensor based DCV, or CO_2-sensor based DCV, is the most profitable depends on absenteeism and utilization of class capacity together with the operation time. Information about use is therefore crucial for optimal design of DCV-systems. [10, 12]. We need knowledge about the use of modern indoor school areas to decide important parameters including density (people/m^2), time of use, operation time of air-handling-units, ventilation system and energy saving potential, optimal sensor choice and ventilation system design. This will be evaluated in this project.

Mysen [13] evaluated a simplified ventilation system with direct air supply through the façade in a school in a cold climate. The school had problems with draughtiness and too low temperatures that hopefully can be mitigated with better tuning of the control system. Use of a combined CO_2- and temperature target seems more appropriate for such ventilation concepts. This is supported by the fact that perceived air quality (PAQ) in the school is better in January than June, which we can assume is mainly caused by a lower indoor air temperature in the breathing zone. Figure 1 shows examples of different control strategies. The figure illustrates our suggested improved control strategy with temperature compensation of the CO_2 set-point. The control can be either linear or stepwise. Both are illustrated.

Implementing such a control strategy could improve thermal comfort and reduce energy use for heating without compromising PAQ during cold weather. In addition it could improve indoor air quality (IAQ) during warm weather with only a slight increase in energy use.

The studies of Fang et al. [14] support this assumption. They studied PAQ, SBS-symptoms and performance of office work at three levels of air temperature and humidity and two levels of ventilation rate (20°C/50% RH, 23°C/50% RH, 26°C/60% RH at 10 ℓ/s per person outside air, and 20°C/40% RH at 3.5 ℓ/s per person outside air). This study shows that the impact of PAQ of decreasing the ventilation rate from 10 to 3.5 ℓ/s per person could be counteracted by a decrement of temperature and humidity from 23°C/50% RH to 20°C/40% RH. Several SBS symptoms were alleviated at low levels of temperature and humidity despite a coincident reduction of ventilation rates. This is consistent with several other studies starting with Wyon [15] demonstrating that warm humid air is perceived as less fresh and less acceptable, and that SBS symptoms such as fatigue and headache may be caused by exposure to air at slightly raised temperature and humidity.

Such a strategy might lead to negative consequences for IAQ related symptoms if the pollution load is considerably influenced by factors such as cleaning standard, emissions from building materials and pollution caused by moisture problems. DCV with CO_2- or temperature-compensated CO_2 control, presuppose that the total pollution load is always dominated by pollution from the occupants, or that the indoor environment is controlled by multisensors. Nano- and microtechnology and industrial production methods have made it possible to produce cheap and robust mulitisensors [16]. The use of temperature-compensated CO_2 control and other intelligent parameter combinations will be investigated further in this project.

Another interesting reflection is that the minimum ventilation rates prescribed in existing ventilation standards do not include the influence of air temperature [17]. These standards can be a barrier to a possibly more optimal ventilation control with temperature-compensated CO_2-set point and the rational basis for this seems dubious. This will be investigated further in this project because it might lead to an unnecessary use of energy during cold weather.

This project focuses on educational buildings, but the results will be applicable for other type of buildings designed for high occupant density.

Methods

The following methods are used:

Literature reviews and focus groups

Critical review will be conducted in the initial stage of the project together with interviews of focus groups will be carried out.

Field studies

Gain relevant knowledge about the use of modern school as basis for evaluate the potential of energy use reduction with DCV.

The results of the field study will be analyzed with statistical tools leading to relevant input data for calculation of energy saving potential controlled for not relevant parameters. The need for sensibility analyses will be continuously considered and, if necessary performed.

The energy saving potential will be analyzed base on the field study results. The variation of the energy potential including relevant uncertainty will be analyzed with statistical tools.

Compose tools

Establish a validated Excel® based tool for simulation of the true reduction in flow rate and fan power in schools, based on the methods described of Mysen (Mysen et al. 2003, Mysen et al 2005) that will serve as appropriate documentation according to the Norwegian building code. The tool should give necessary input data for design, management and maintenance of the DCV system.

Establish guidelines and an Excel based cost-benefit tool for decision makers applicable in the early stage of a project.

Establish system specifications, hand-over documents and balancing report suitable for DCV.

Validation in field and laboratory

Validate the calculation tools through pilot studies and field and laboratory measurements.

Observations and Discussion

There are several factors influencing robustness and energy use related to DCV. The most important factors are:

- Target values (e.g. fresh air flow rates)
- Occupancy and activity
- Design (duct layout, VAV/CAV mixing, ventilation principle)
- Control systems (actuators, sensor location, algorithms and control strategy)
- Sensors (reliability and accuracy, location)
- Communication systems (protocols, transfer rate)

All these factors and their interactions are affected by a rapid development based on knowledge and available technology. There are several different system solutions based on pressure control, flow control, damper position control with and without optimizer and self regulating DCV diffusers.

In addition, you might have value-added functionality if the sensors control other energy related technology such as artificial lighting, solar shading, heating-/cooling systems and log data about actual use of the rooms/areas.

Although theoretical studies show that energy use for ventilation purposes can be reduced by more than 50% with DCV compared with CAV. Evaluation of real energy use demonstrates that this potential is seldom met. DCV-based ventilation systems must become more reliable to close the gap between theoretical and real energy-performance.

This unfortunate experience with DCV seems to have many causes like:

- unclear placement of responsibility for the overall system functionality
- inadequate specifications and hand-over documentation
- balancing report not suitable for DCV

- components and room-level control that work autonomously but do not communicate properly with BEMS
- lack of knowledge about DCV-systems and components throughout the whole chain from decision makers to operating personnel
- wiring mistakes
- programming errors
- defect sensors or unfortunate placement of them.

This implies that future systems should have some kind of inherent functionality to detect, diagnose and repair faults before it leads to adverse health and energy consequences.

The following success criteria’s for well functioning and economical beneficial DCV have been identified through introductory interviews:

- Responsibility for the overall system functionality is clearly defined and placed

- Knowledge about DCV among decision makers, designers, contractors and operating personnel. It’s especially crucial that it is designed by an HVAC-consultant with up-to-date expertise within DCV
- Interactive systems communicate smoothly
- Adequate specifications, hand-over documentation and balancing report for DCV have been used
- Components, such as sensors, that have proper functionality and quality throughout their predicted lift expectancy
- Possibility to control the function of crucial components such as fan energy use, VAV-damper positions, air flows at room level etc.
- Maximum diversity factors use for dimensioning and assumed average use for energy calculations, together with specified running conditions during control procedure.
- Prospective economical penalty is agreed upon before performance test during final control procedure

Summary and conclusions

This paper presents initial and coming studies of a recently started project that aims to develop and disseminate knowledge on systems with improved robustness.

Evaluation of real energy use of DCV-systems demonstrates that theoretical potential for energy reduction is seldom met. DCV-based ventilation systems must become more reliable to close the gap between theoretical and real energy-performance.

This unfortunate experience with DCV seems to have many causes. Optimal indoor environment with a minimum use of resources (eq. energy) requires well-functioning DCV. Some success criteria for well functioning and economical beneficial DCV are identified and described above. The following topics will be investigated further:

- *Actual use of modern indoor school areas related to density (people/m^2), time of use, operation time of air-handling-unit*
- *Evaluation of different DCV solutions regarding robustness, energy use and reliable ventilation rates.*
- *Optimal ventilation system design and sensor choice*
- *Use of temperature-compensated CO_2 control and other parameter combinations*

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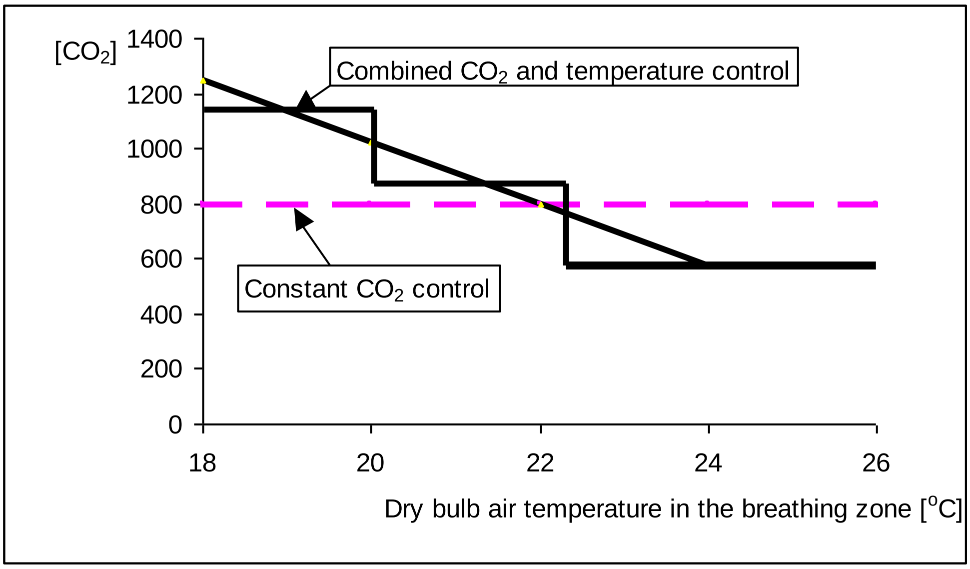

Fig. 1 Three different control strategies for DCV. The conventional constant CO_2 control and the suggested improved control strategy with linear or stepwise temperature compensated CO_2 set-point.